Lecture 21: Microscopic Particle Image Velocimetry technique (Micro-PIV - Part 02)

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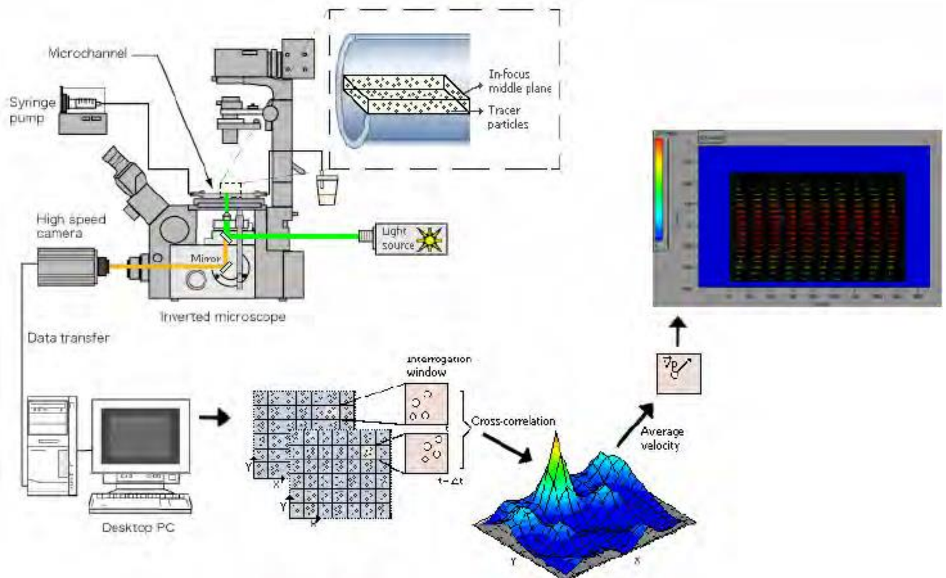
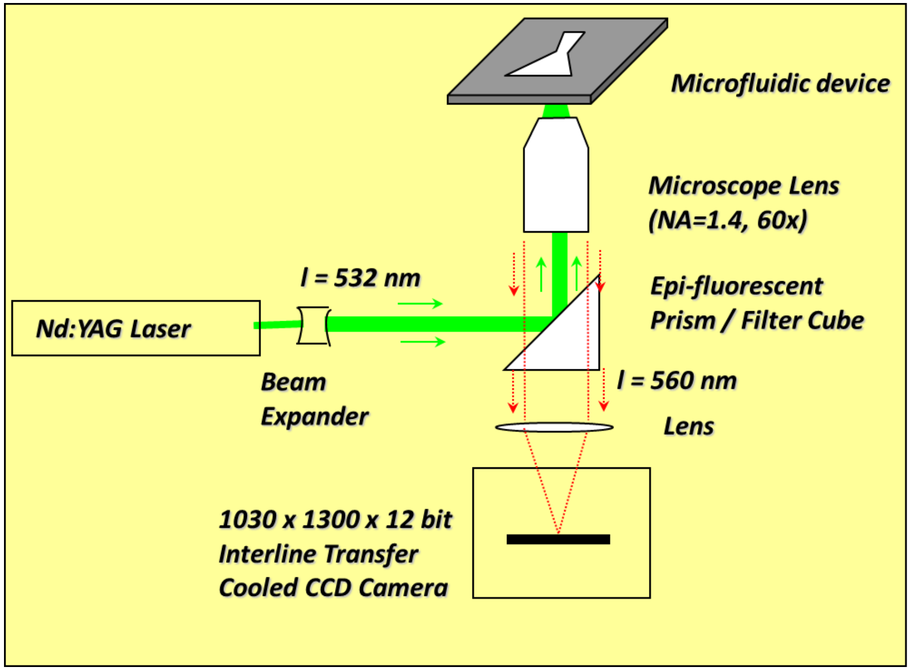
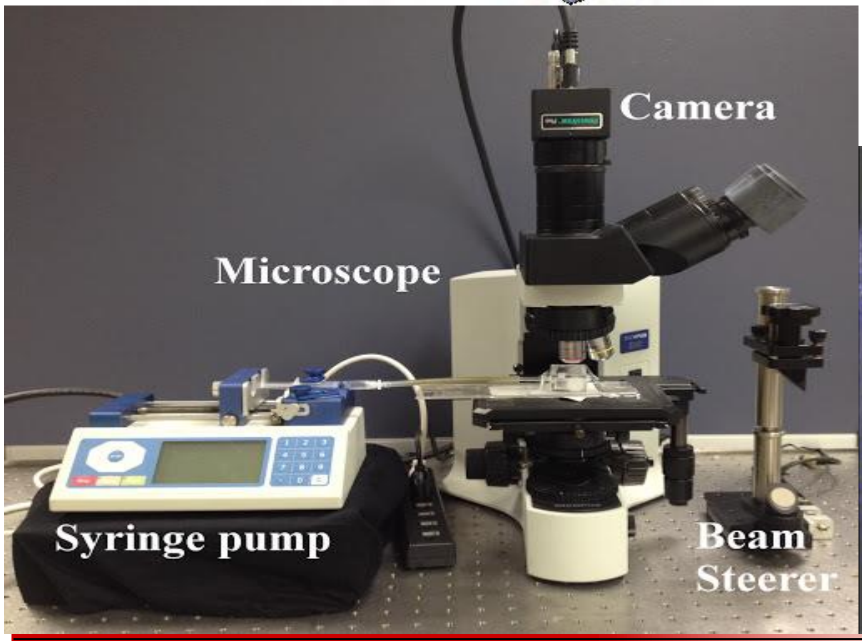
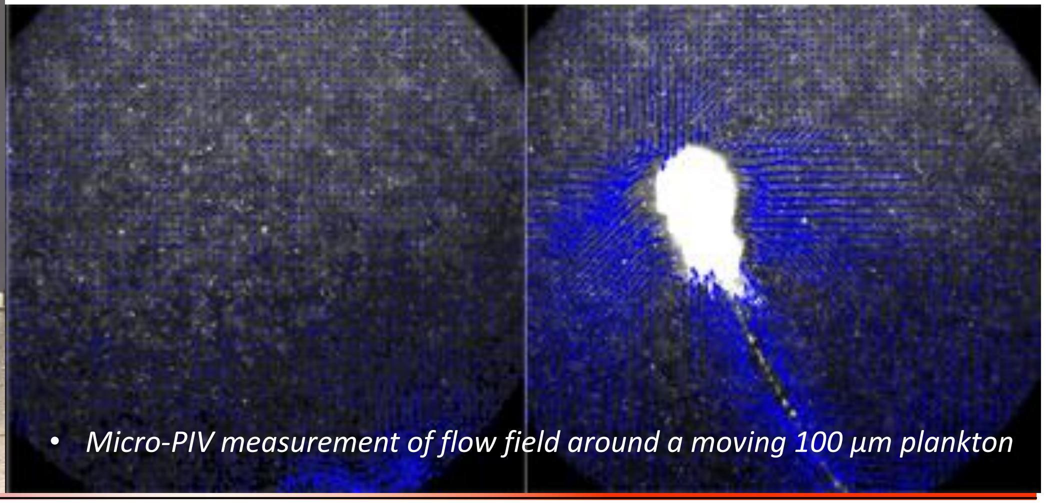
System Setup of a Typical Micro- PIV system

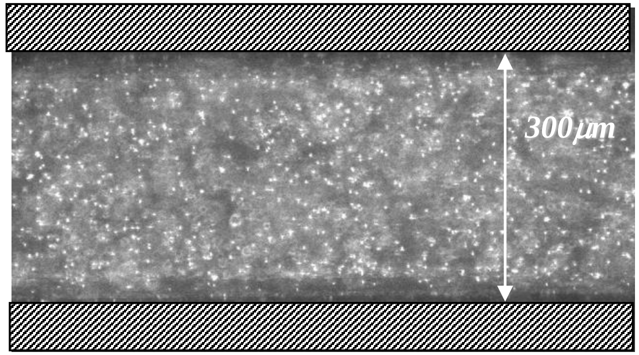


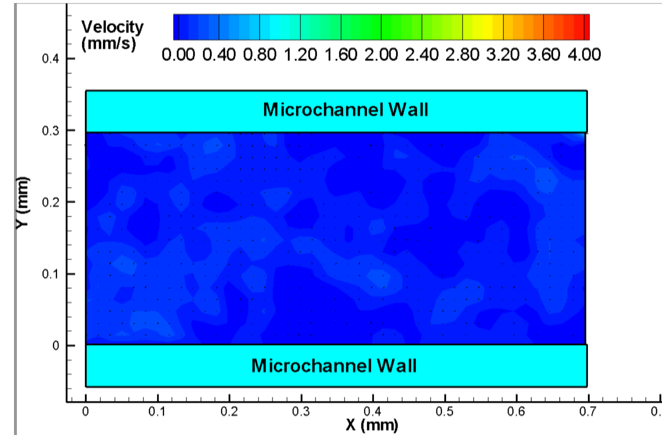






- *Micro-PIV measurement of flow field around a moving 100 μm plankton*





Experimental and Theoretical studies of Pulsed Micro Flows Pertinent to Continuous Subcutaneous Insulin (CSII) Therapy

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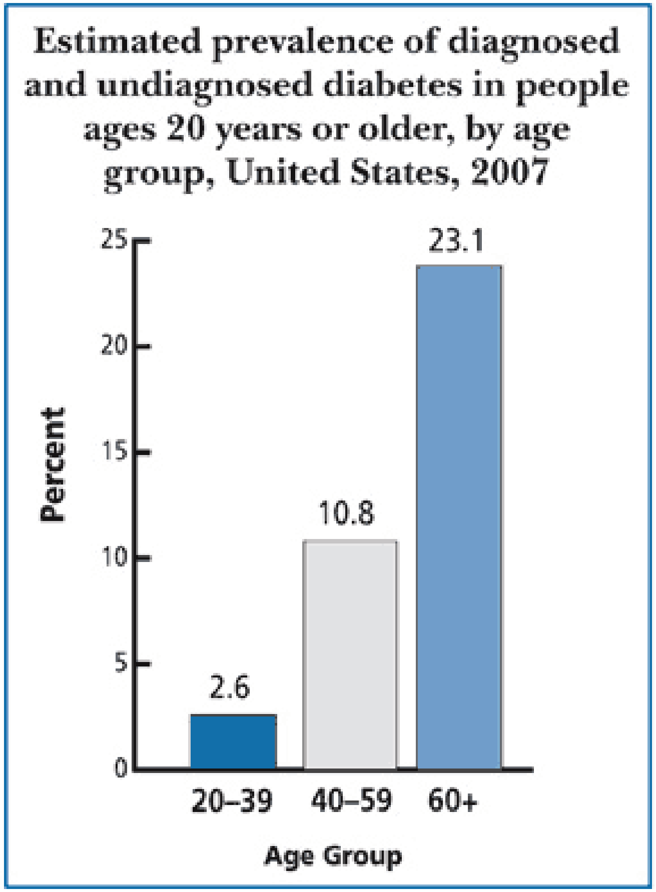
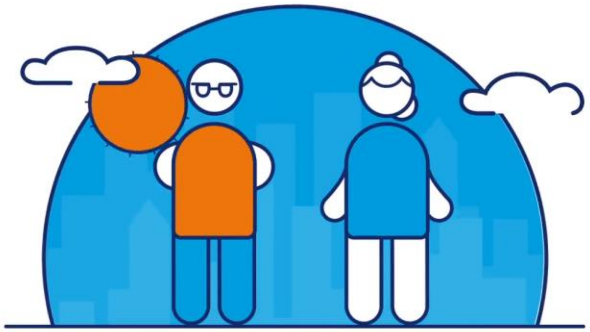
Diabetes



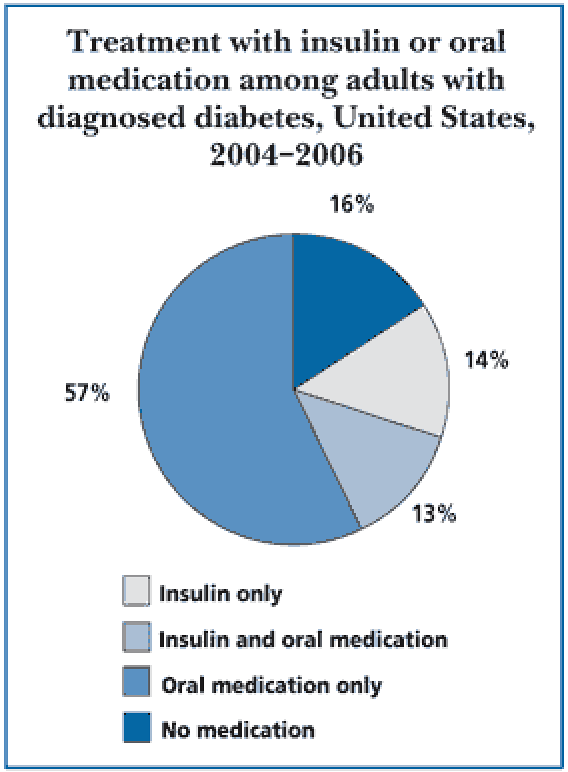
Source: 2003–2006 National Health and Nutrition Examination Survey estimates of total prevalence (both diagnosed and undiagnosed) were projected to year 2007.

- ***Type 1 diabetes***
  - *the body does not produce insulin*
  - *usually diagnosed in children and young adults*

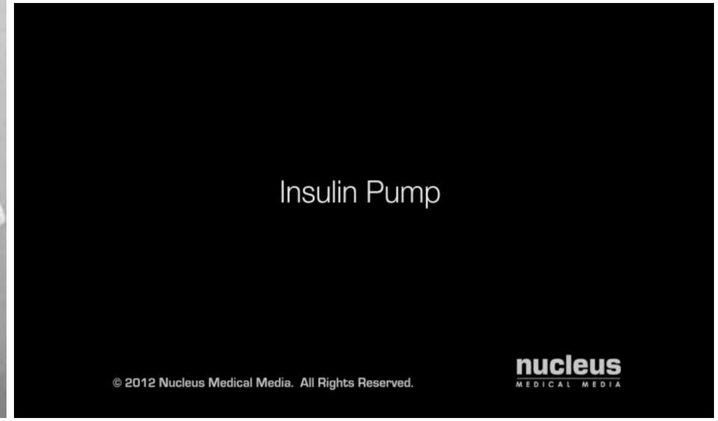
- ***Type 2 diabetes***
  - *either the body does not produce enough insulin or the cells ignore the insulin*
  - *the most common form of diabetes*



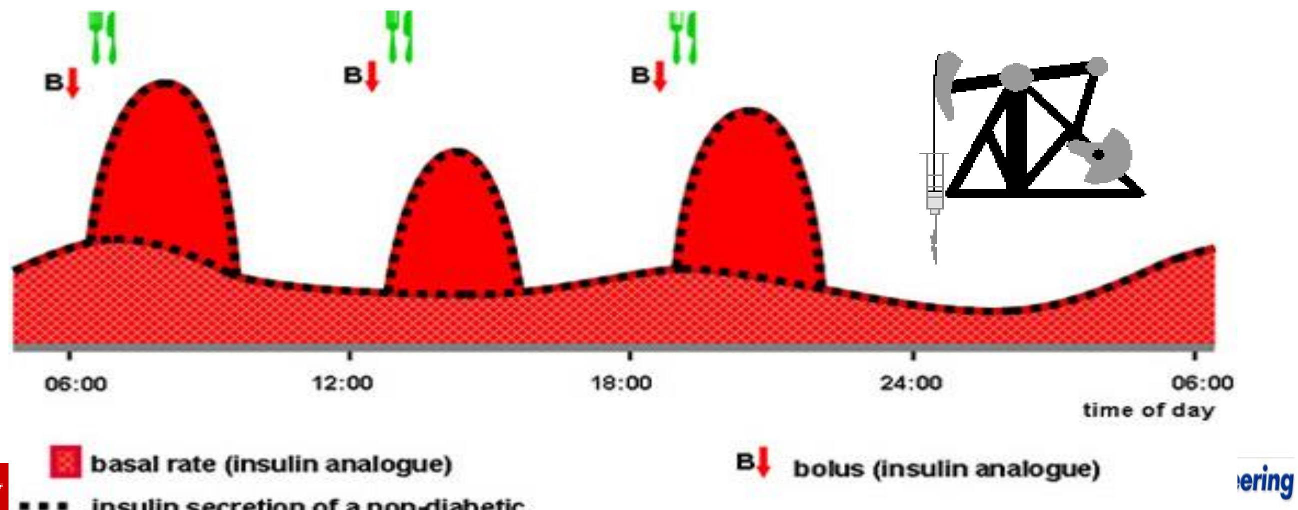
❑ Continuous Subcutaneous Insulin Infusion (CSII)



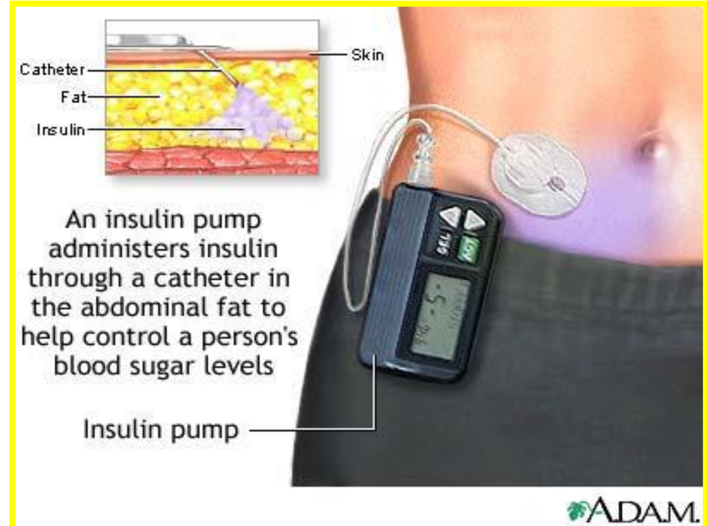
Source: 2004–2006 National Health Interview Survey.



- ***Multiple Daily Injection (MDI) therapy***
- ***Continuous Subcutaneous Insulin Infusion (CSII) Therapy***



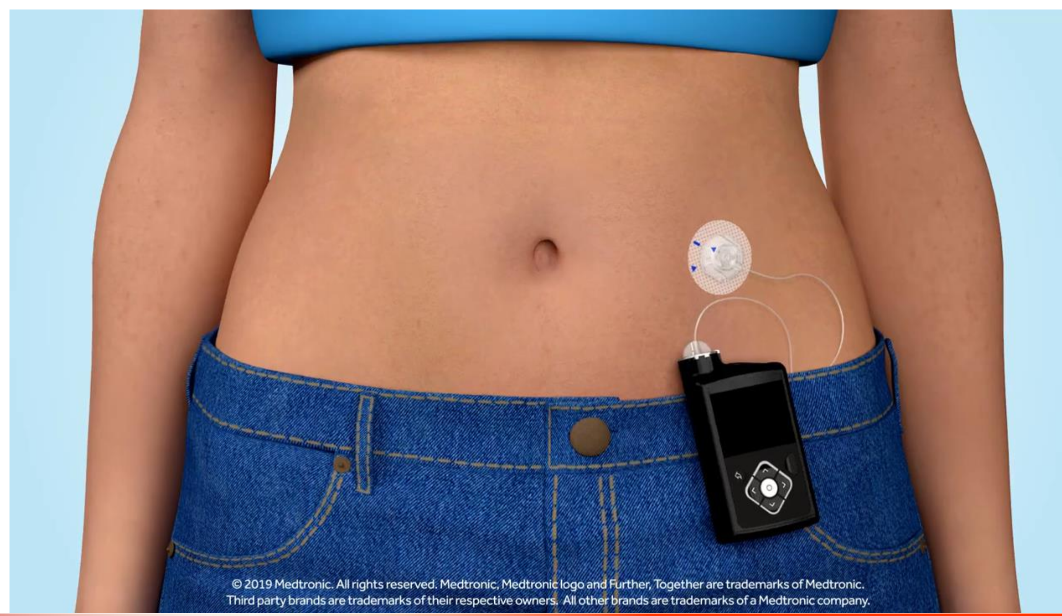
CSII vs. MDI



Multiple Daily Injection (MDI) therapy

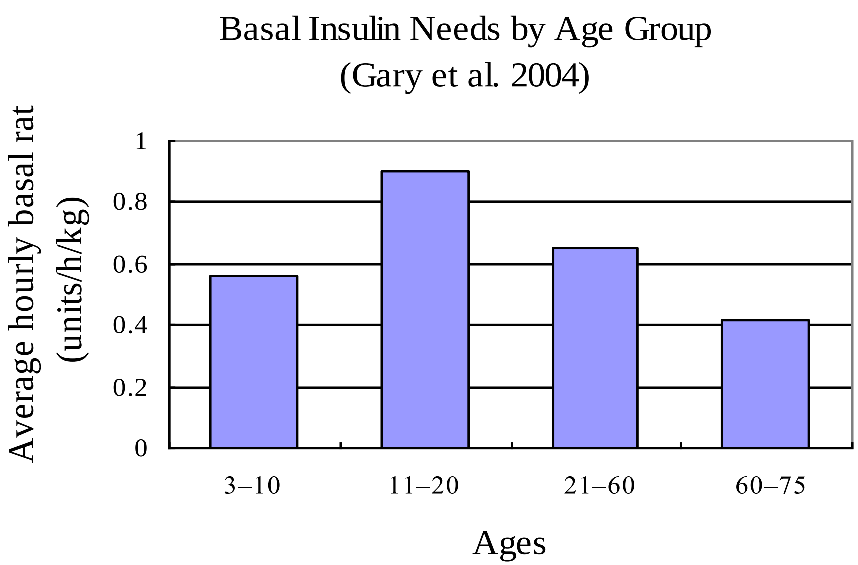
Continuous Subcutaneous Insulin Infusion (CSII) Therapy

1 Unit Insulin~10 mm^3



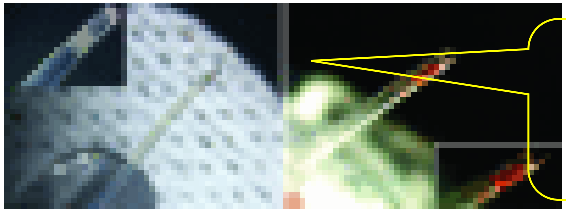
❑ Occlusion of insulin delivery

Insulin Delivery Shortage at low basal rates



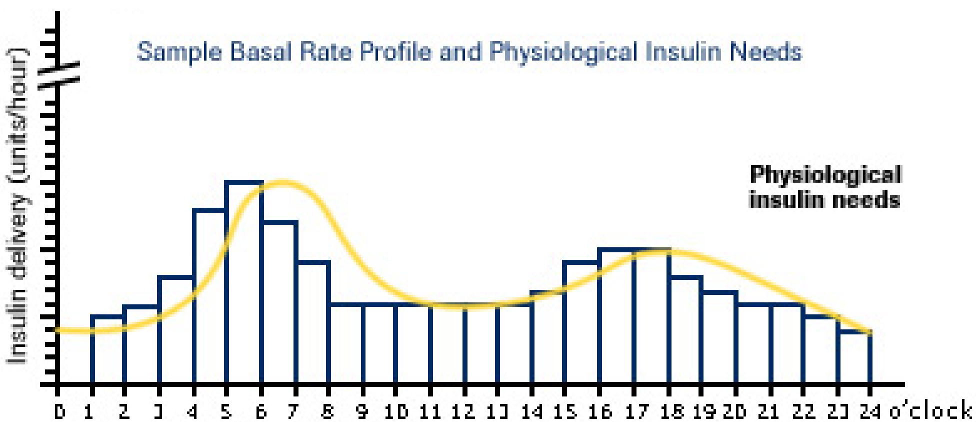
What is a silent occlusion in
insulin pump therapy?

This is a simulation.



Catheter occlusion

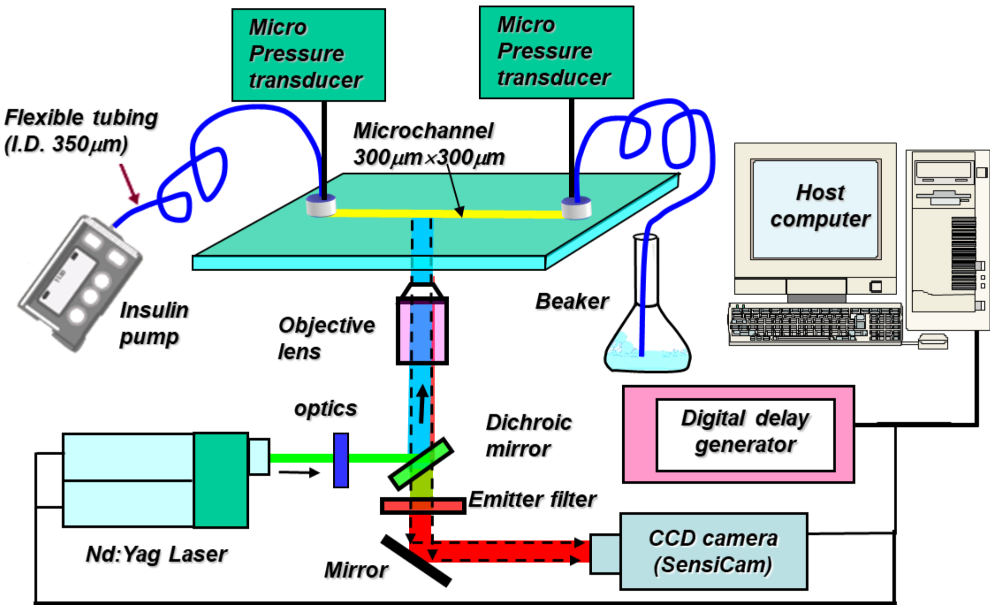
Air bubble
0.1Unit~ 1mm³

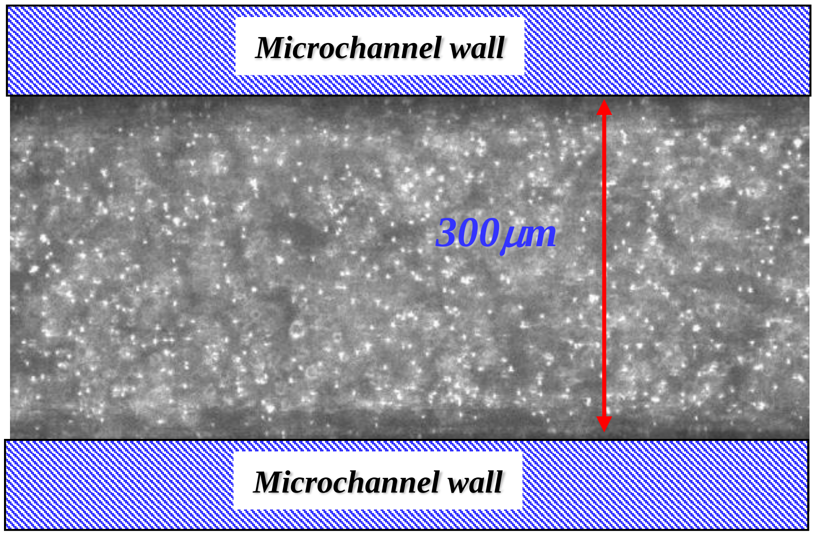


1 Unit Insulin~10 mm³

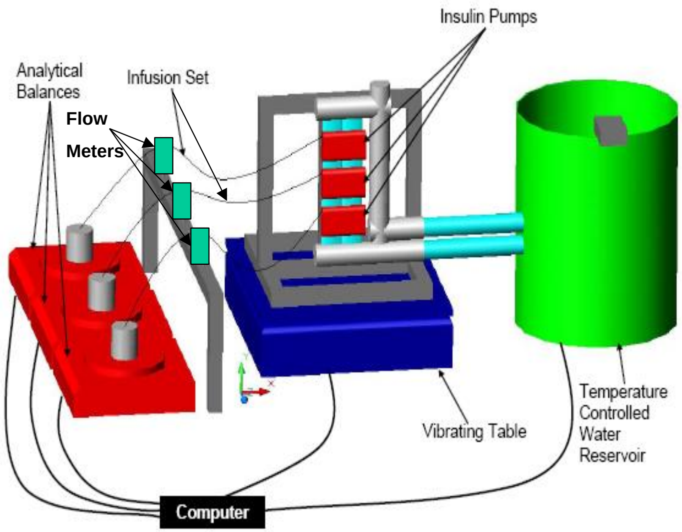
Objective of the present study

- *Currently, most solutions to insulin occlusion related problems are based on clinical trials.*
- *It is of great value to elucidate underlying physics of insulin infusion process, from the pump action to the catheter delivery, and from a fluid dynamics perspective, in order to provide a better guidance for troubleshooting.*
- *Theoretical equations were derived to model the unsteady micro-flows inside a microchannel driven by an insulin pump commonly used in CSII therapy.*
- *A high-resolution micro-PIV system is used to conduct detailed flow velocity field measurements to characterize the transient behavior of the unsteady micro-flows inside a micro-sized capillary infusion tubing system commonly used in CSII therapy.*
- *The objective of the study is to elucidate underlying physics for a better understanding of the microphysical process associated with the insulin delivery in CSII therapy in order to provide a better guidance for troubleshooting of insulin occlusion in CSII therapy.*



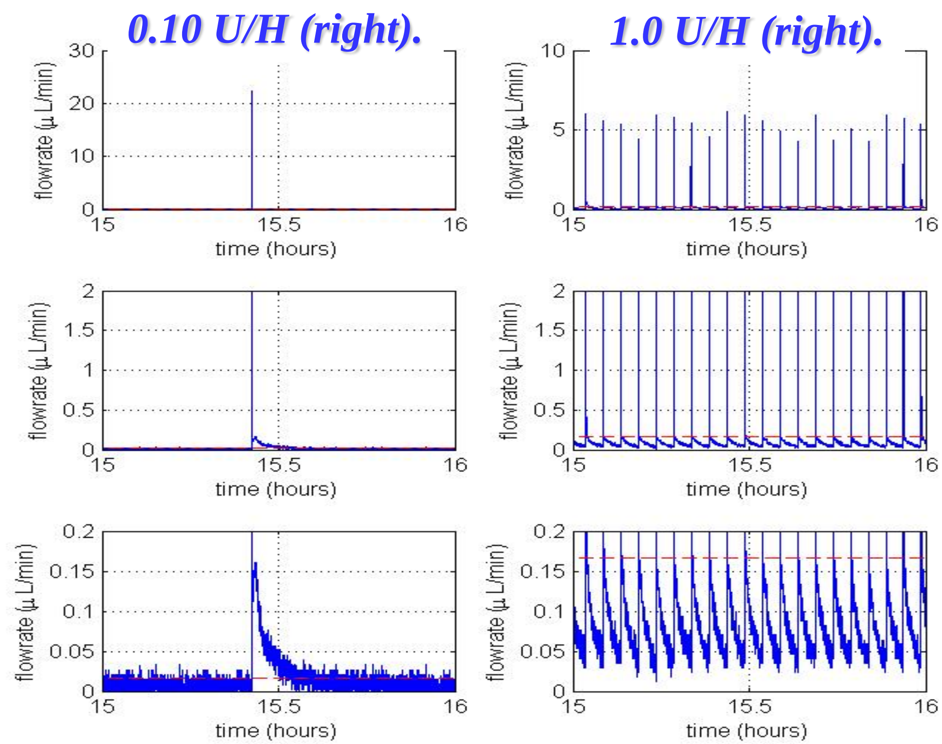


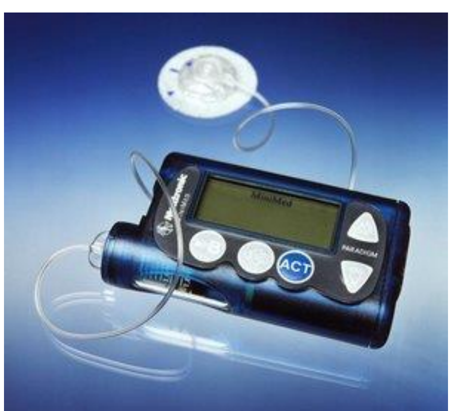
Pulsed Micro Flows driven by Insulation Pumps

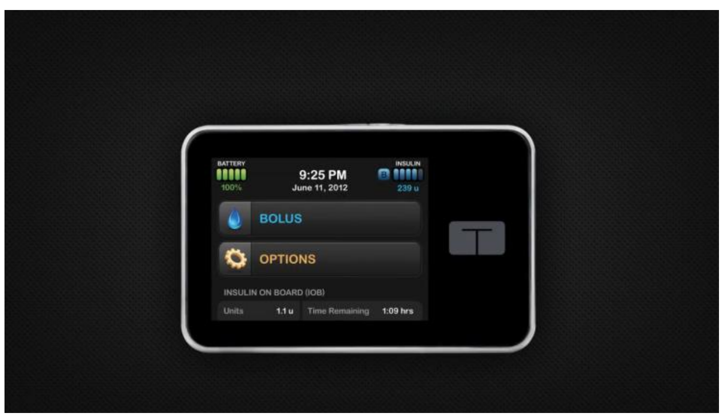


Demuren et al. @ODU

- *Bulk measurement.*
- *Delivery rate of insulin*

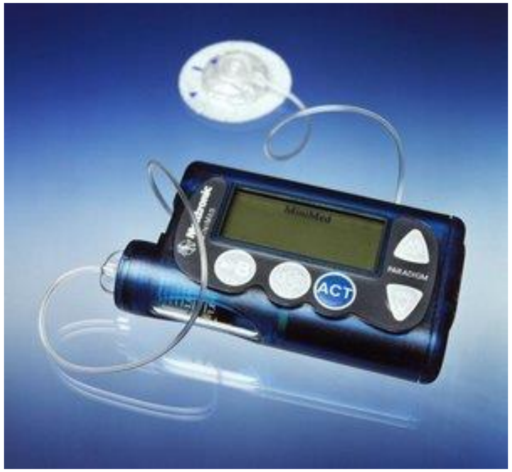




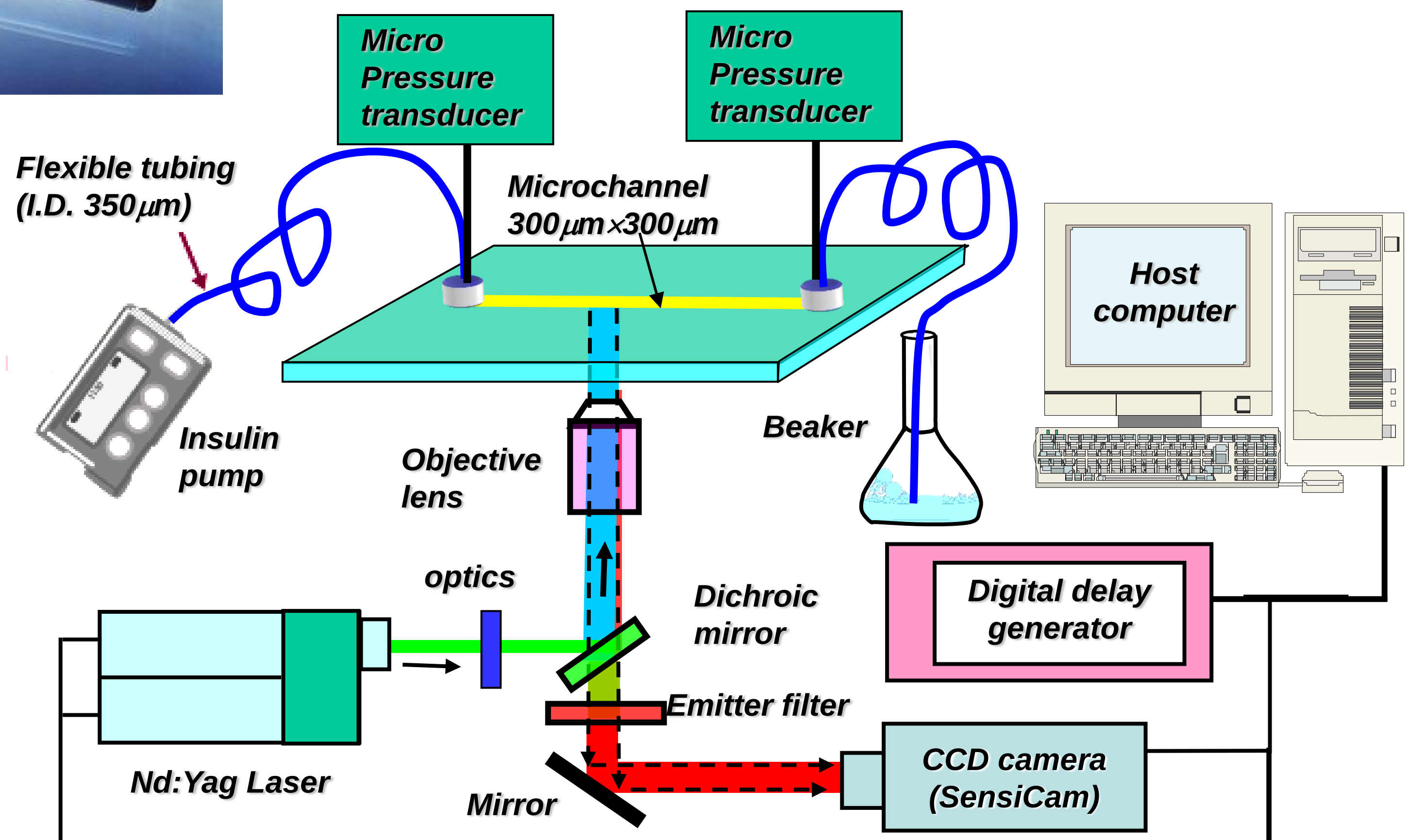


- ***Measured instantaneous flow rates for insulin pumps set to basal dosage of 0.1 U/H (left) and 1.0 U/H (right).***
- ***Dashed lines indicate average flow rates.***

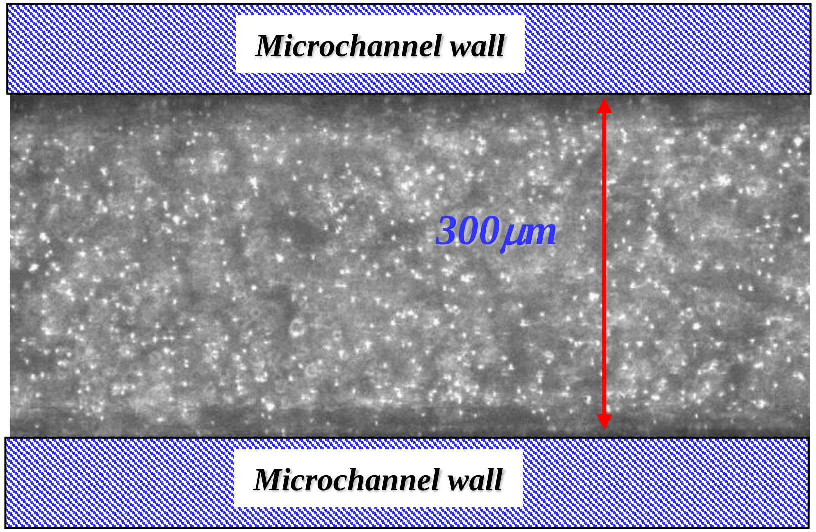
A Study of Insulin Occlusion Using Insulin Pump

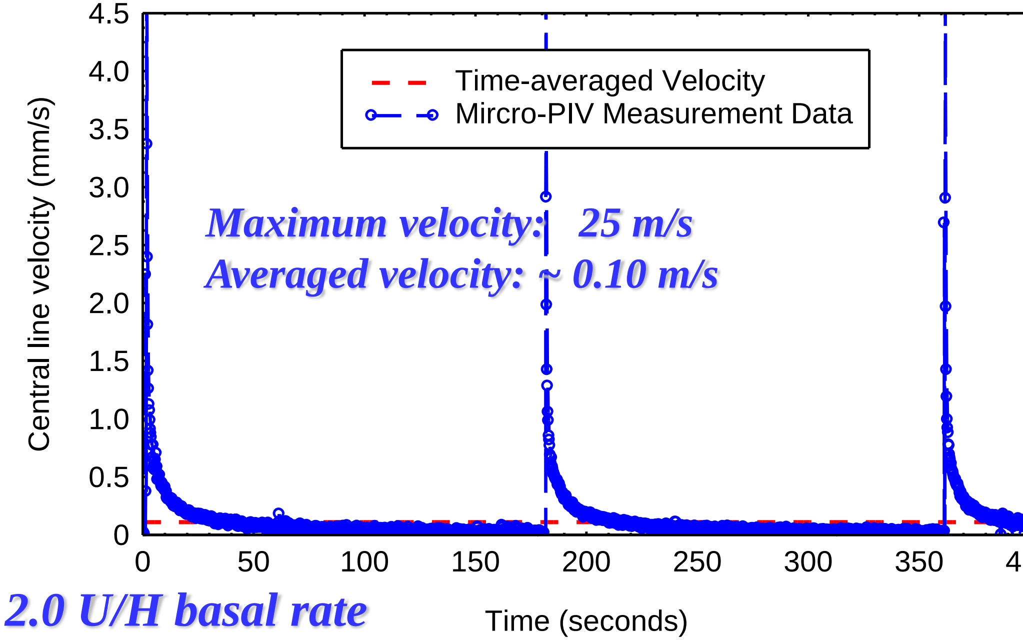


- Working fluid: DI water
- Nile red fluorescent FluoSpheres® (535/575nm, ~ 1 μm)
- Laser: 532 nm, 5~10 Hz
- 20X objective lens (NA=0.4)
- CCD: 1376 $\times$ 1040 pixels (~1.08 μm/pixel)

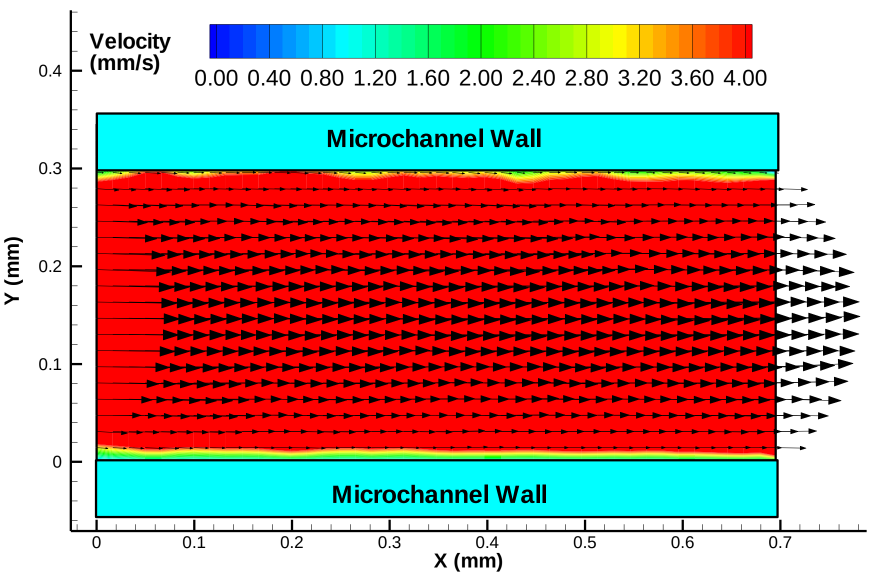


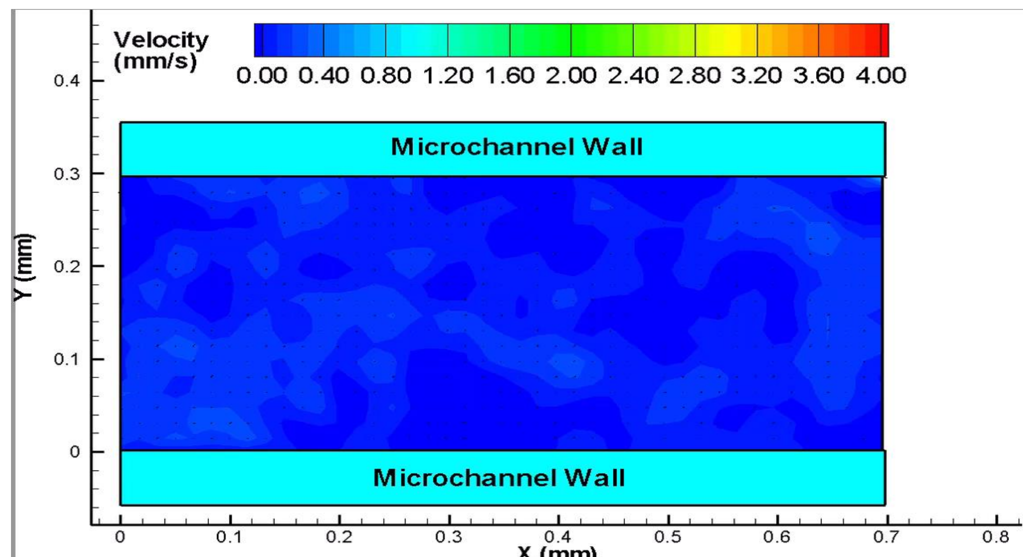
Micro-PIV Measurement Results



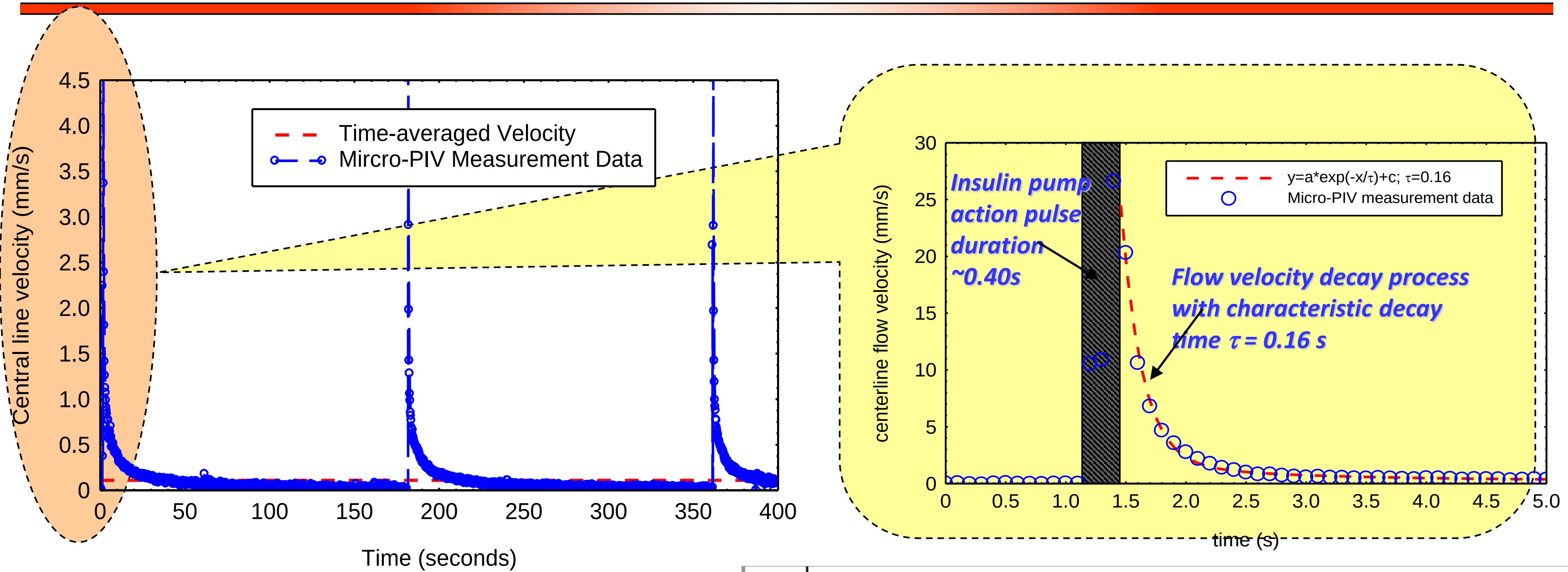


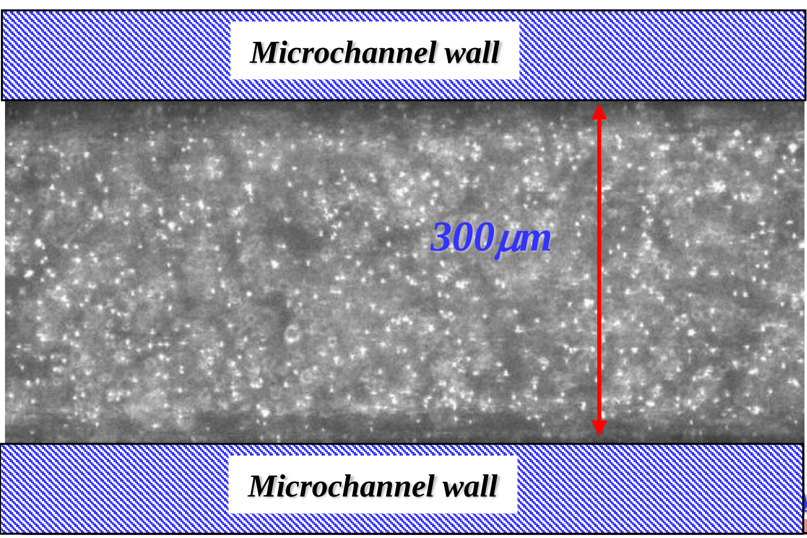
2.0 U/H basal rate

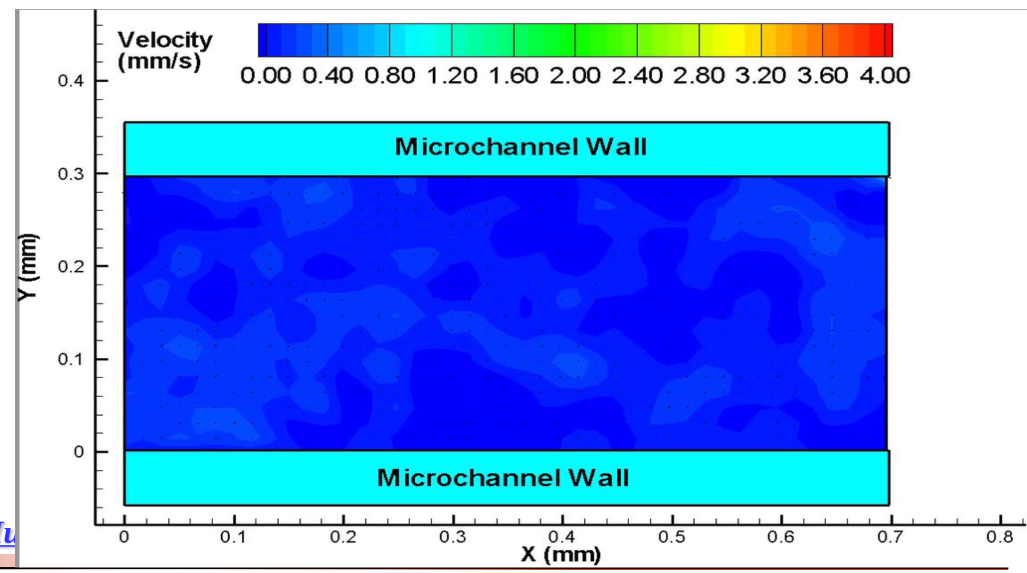




Micro-PIV Measurement Results







Theoretic Modeling of Pulsed Flows in Microchannels

Assumptions:

- ***Incompressible and Newtonian fluid with constant physical properties***
- ***Gravity effects are negligible***
- ***Pressure gradient is non-zero along flow direction (X-direction) only.***
- ***Flow velocities in the Y and Z directions are zero (i.e., Uni-directional flow).***

Governing equation:

$$\frac{\partial u}{\partial x} = 0 \quad \Rightarrow \quad u = u(y, z, t)$$

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

- ***Initial condition:***

$$u(y, z, t) = 0 \quad @\, t = 0$$

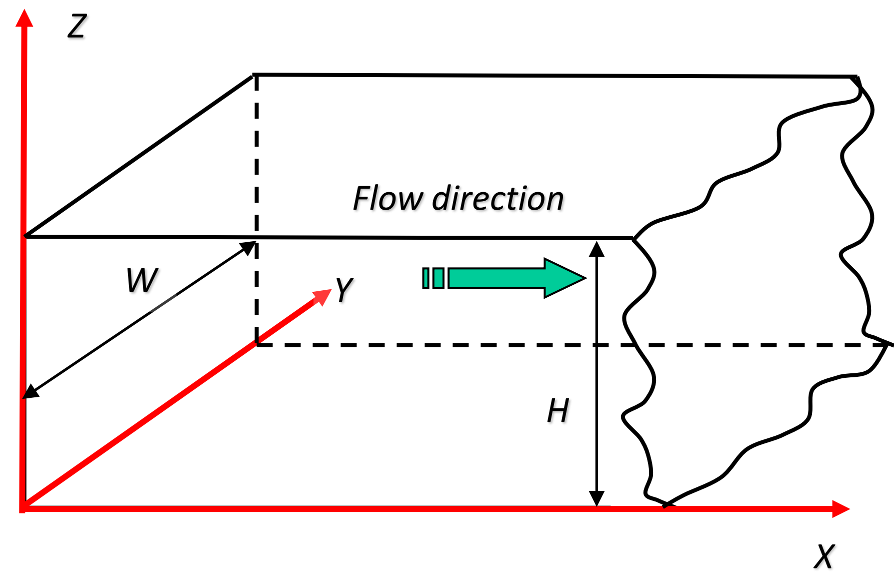
- ***No slip boundary conditions at the wall***

$$u(y, z, t) = 0 \quad @\, y = 0$$

$$u(y, z, t) = 0 \quad @\, y = w$$

$$u(y, z, t) = 0 \quad @\, z = 0$$

$$u(y, z, t) = 0 \quad @\, z = h$$



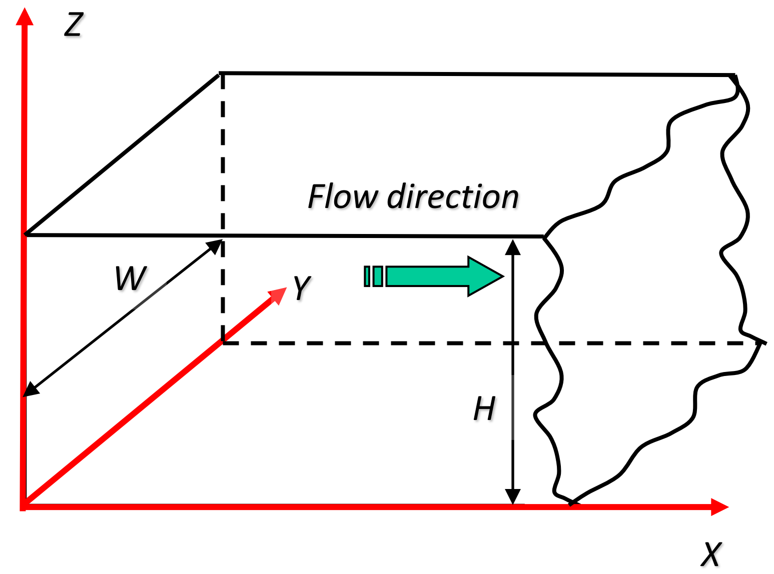
Theoretic Modeling of Pulsed Flows in Microchannels

since : $u = u(y,z,t)$ ***and***

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$\Rightarrow \frac{1}{\rho}\frac{\partial P}{\partial x} \text{ is only a function of time}$$

i.e.: $\frac{1}{\rho}\frac{\partial P}{\partial x} = f(t)$



Therefore, the governing equation can be re-written as:

$$\frac{\partial u}{\partial t} = f(t) + \nu\left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

Following the work of Qi et al. (2008), the solution of the above equation can be expressed :

$$u(y,z,t) = \int_0^t f(\tau) G_u(y,z,t-\tau)\,d\tau$$

Where :

$$G_u(y,z,t) = \frac{16}{\rho\pi^2}\sum_{n=0}^{\infty}\sum_{m=0}^{\infty}\frac{e^{-\nu\lambda^2{}_{mn}t} S_{2m+1,2n+1}}{(2m+1)(2n+1)}$$

$$\lambda^2{}_{nm} = \pi^2\left[\frac{(2m+1)^2}{W^2} + \frac{(2n+1)^2}{H^2}\right]$$

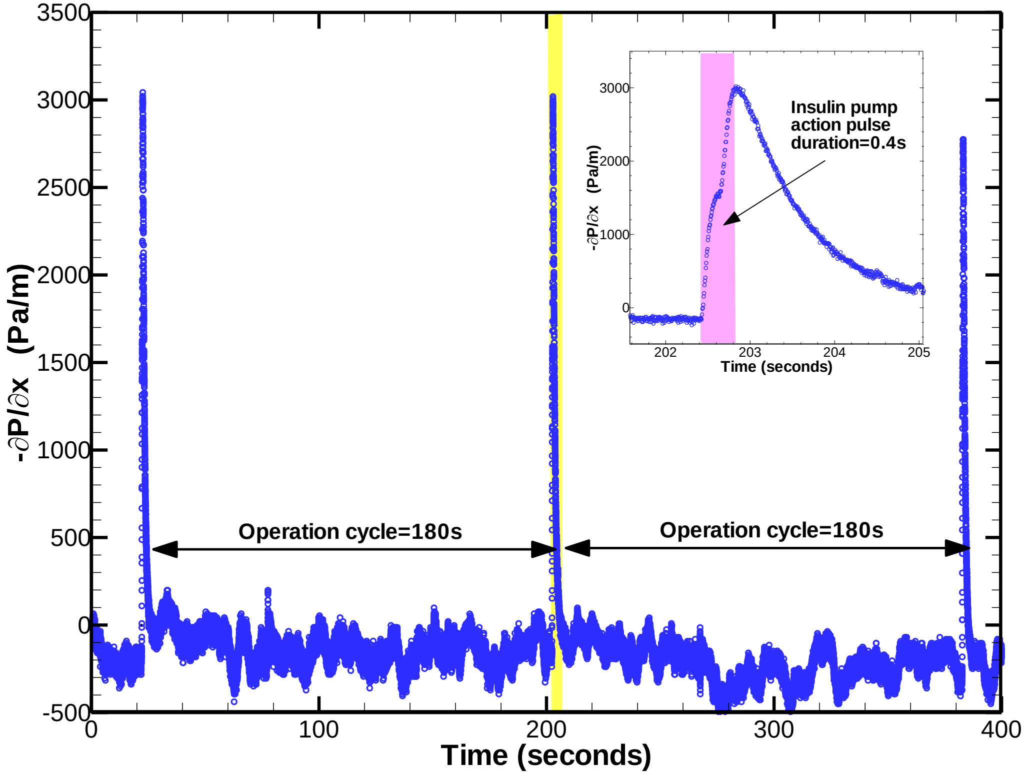
$$S_{2m+1,2n+1} = \sin\frac{(2m+1)\pi\, y}{W}\sin\frac{(2n+1)\pi\, z}{H}$$

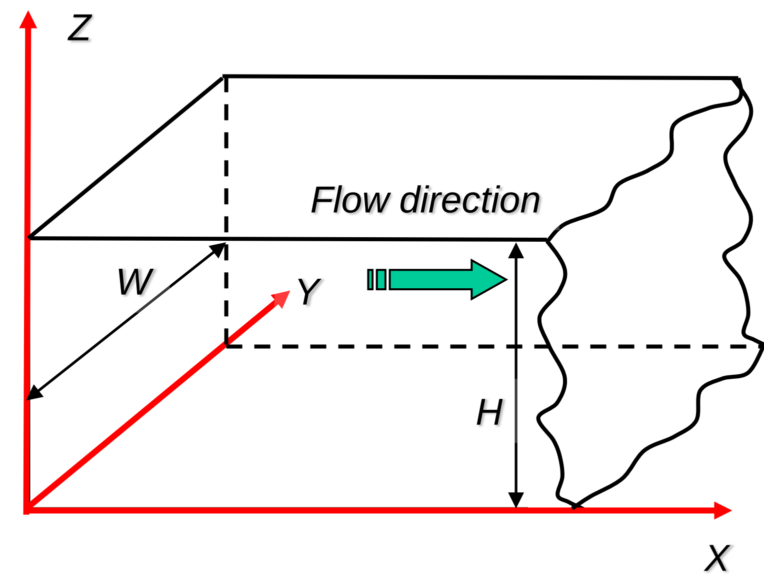
Theoretic Modeling of Pulsed Flows in Microchannels

Therefore, the theoretical solution of the flow inside the micro channel will be :

$$U(y,z,t)=\frac{16}{\rho\pi^2}\sum_{n=0}^{\infty}\sum_{m=0}^{\infty}\frac{\sin\frac{(2m+1)\pi}{2}\sin\frac{(2n+1)\pi}{2}}{(2m+1)(2n+1)}\int_0^t f(\tau)e^{-\nu\lambda^2_{mn}(t-\tau)}d\tau$$

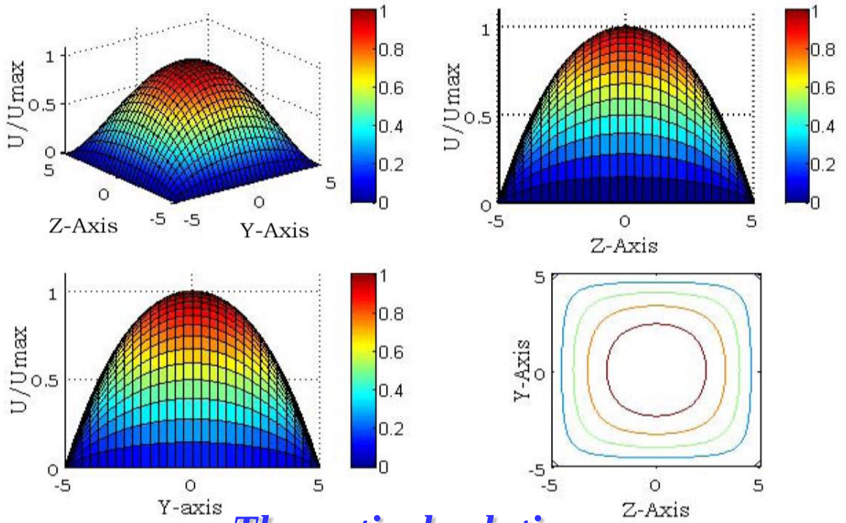
$$where: \quad f(t)=\frac{1}{\rho}\frac{\partial P}{\partial x}$$

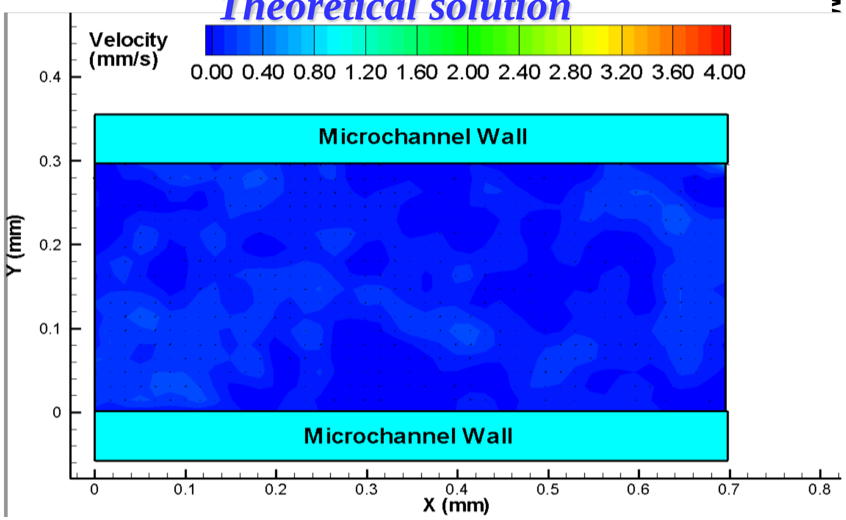




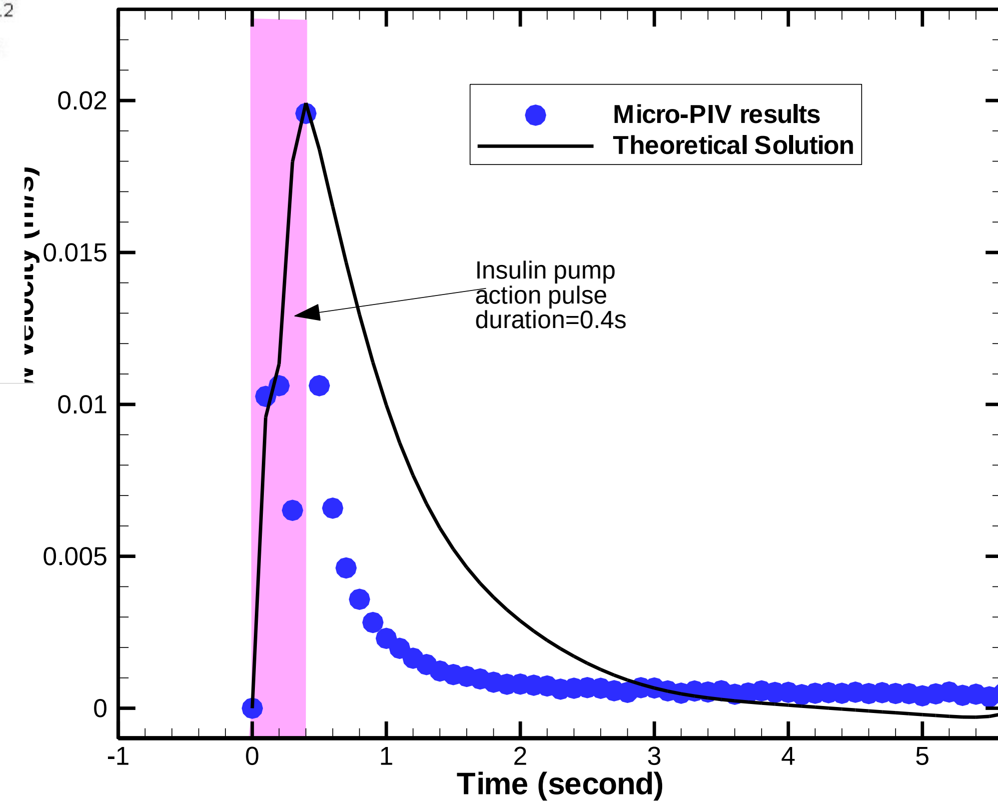
The measured transient pressure gradient inside the CSII tubing system

Comparison between theoretic predictions and measurement results





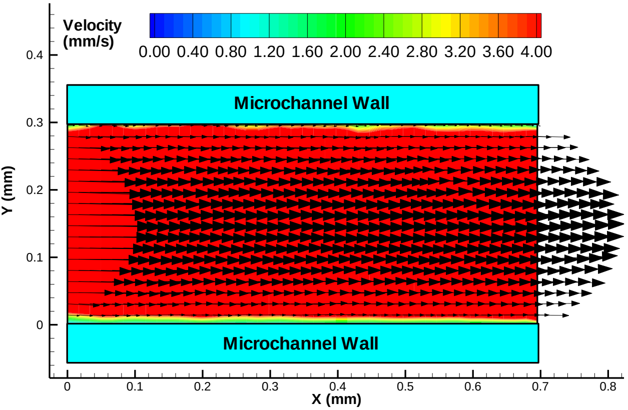
Micro-PIV measurement results



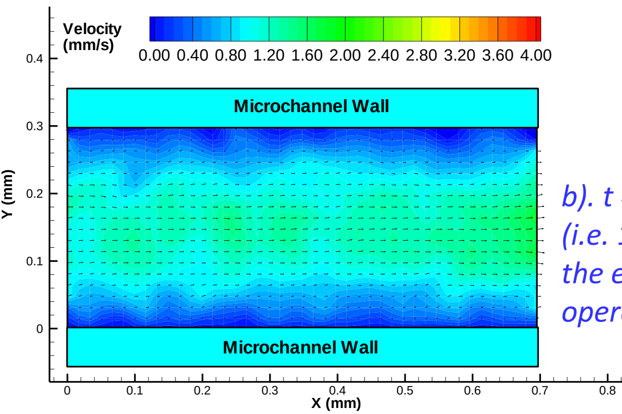
Decay of the centerline velocity

- ***Wang B, Demuren A, Gyuricsko E, <u>Hu H</u>***, *"An Experimental Study of Pulsed Micro Flows Pertinent to Continuous Subcutaneous Insulin Infusion Therapy", Experiments in Fluids, Vol. 51, No. 1, pp65-74, 2011*

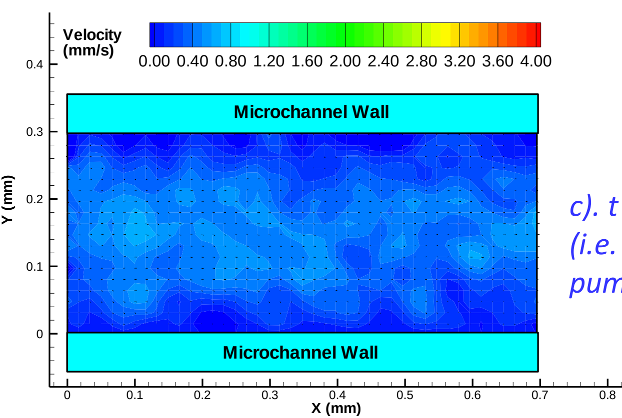
Micro-PIV Measurement Results



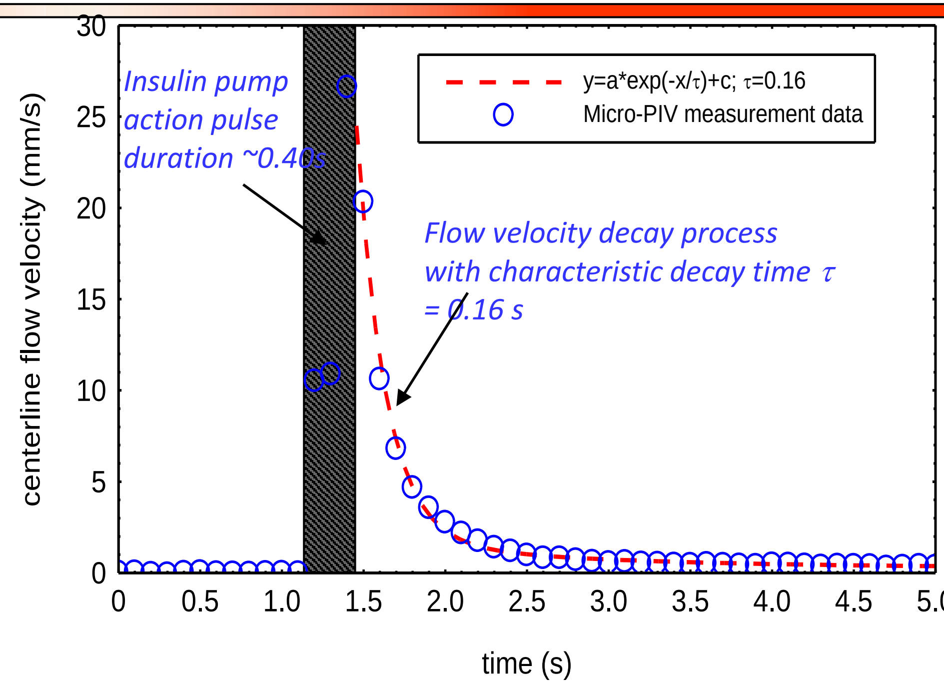
a). t = t_0 (i.e. At the end of pump operation pulse)

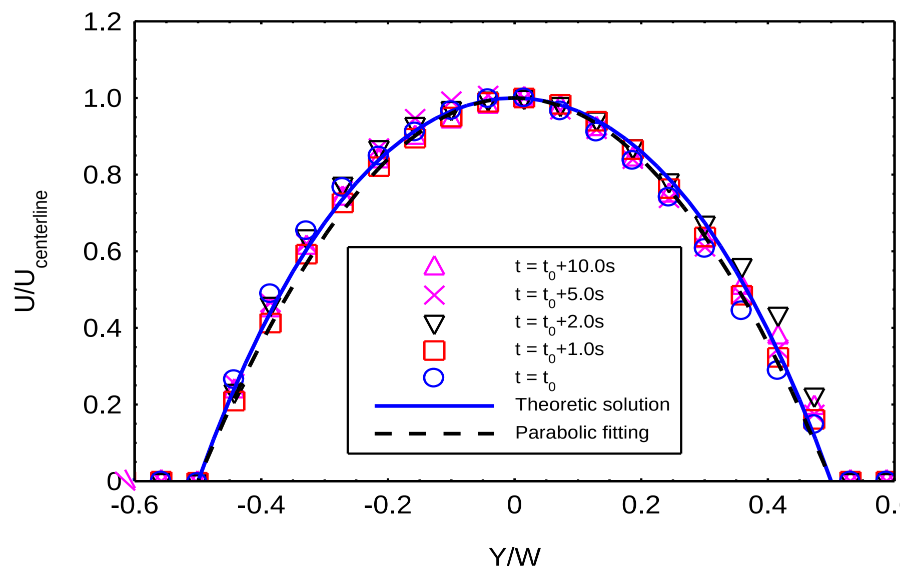


b). t = t_0 +1.0 s (i.e. 1.0 s after the end of pump operation pulse)

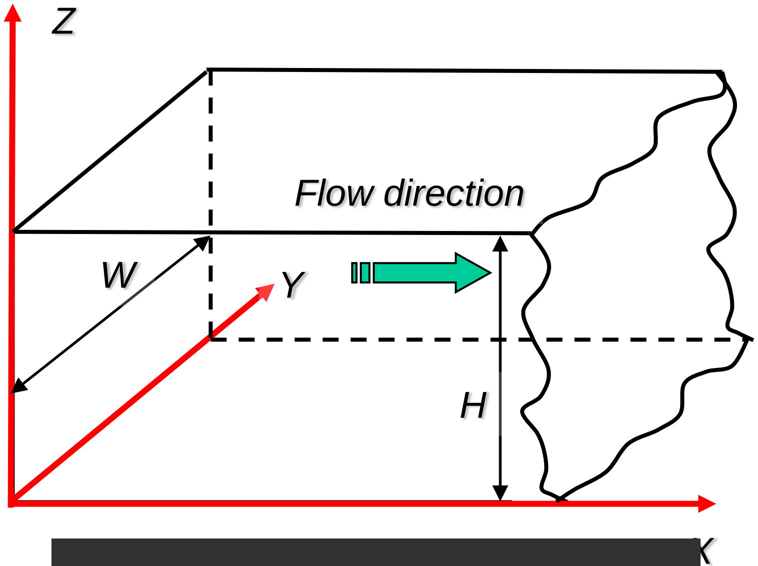


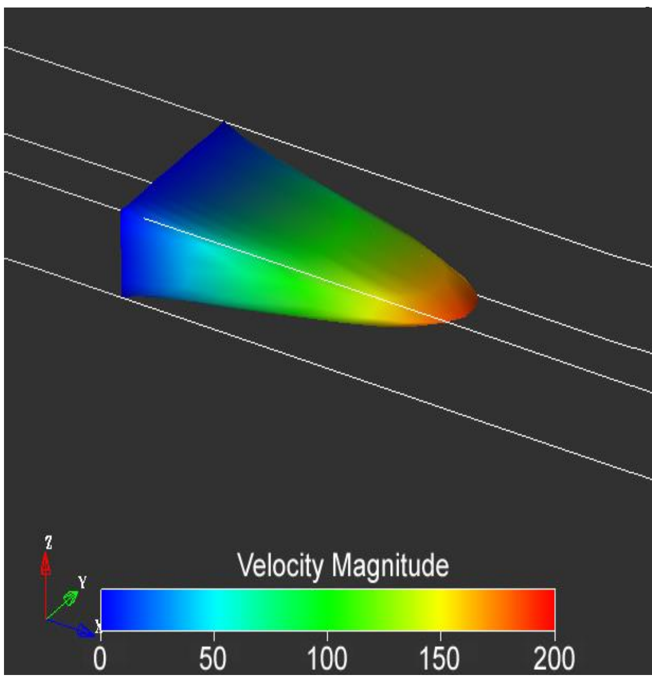
c). t = t_0 +5.0 s (i.e. 5.0 s after the end of pump operation pulse)

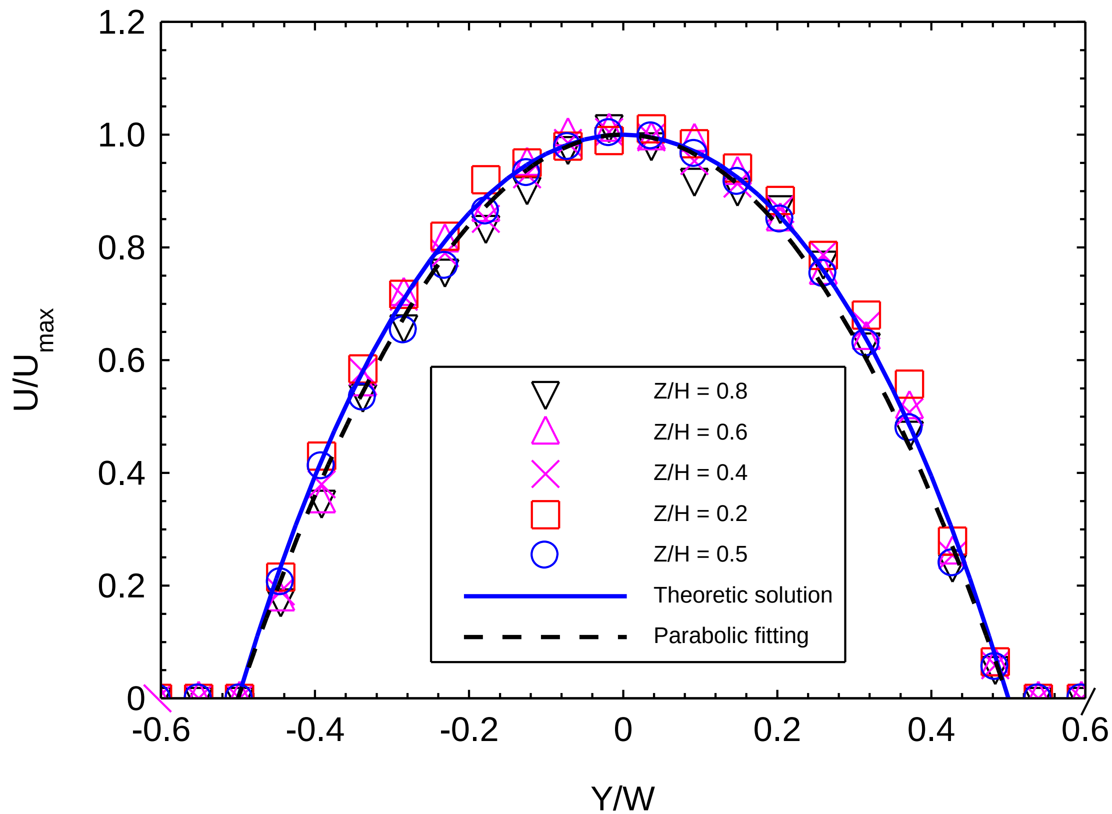




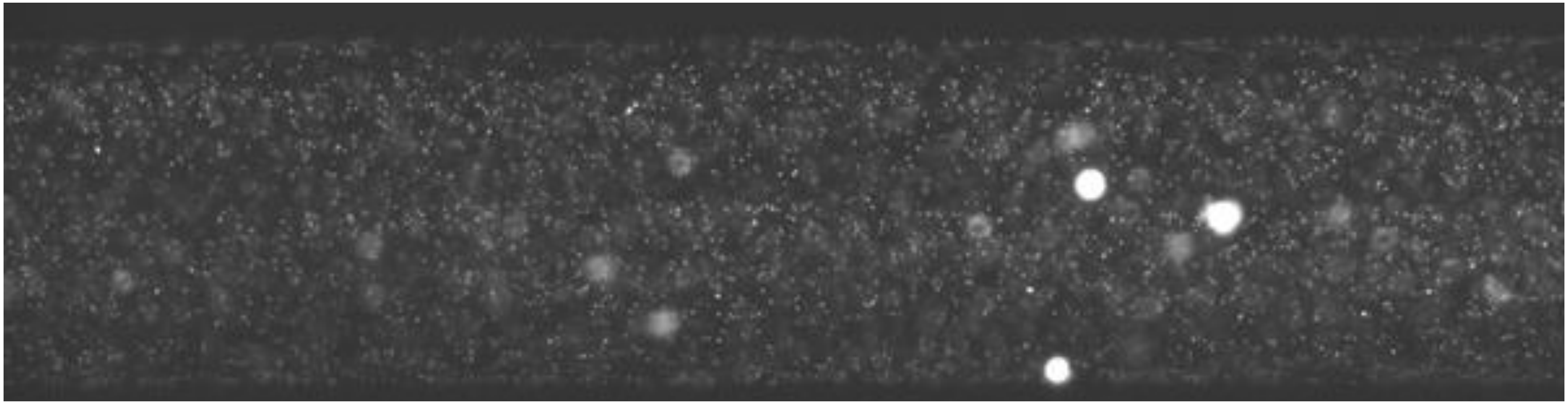
Velocity Profiles in the cross planes at different depth

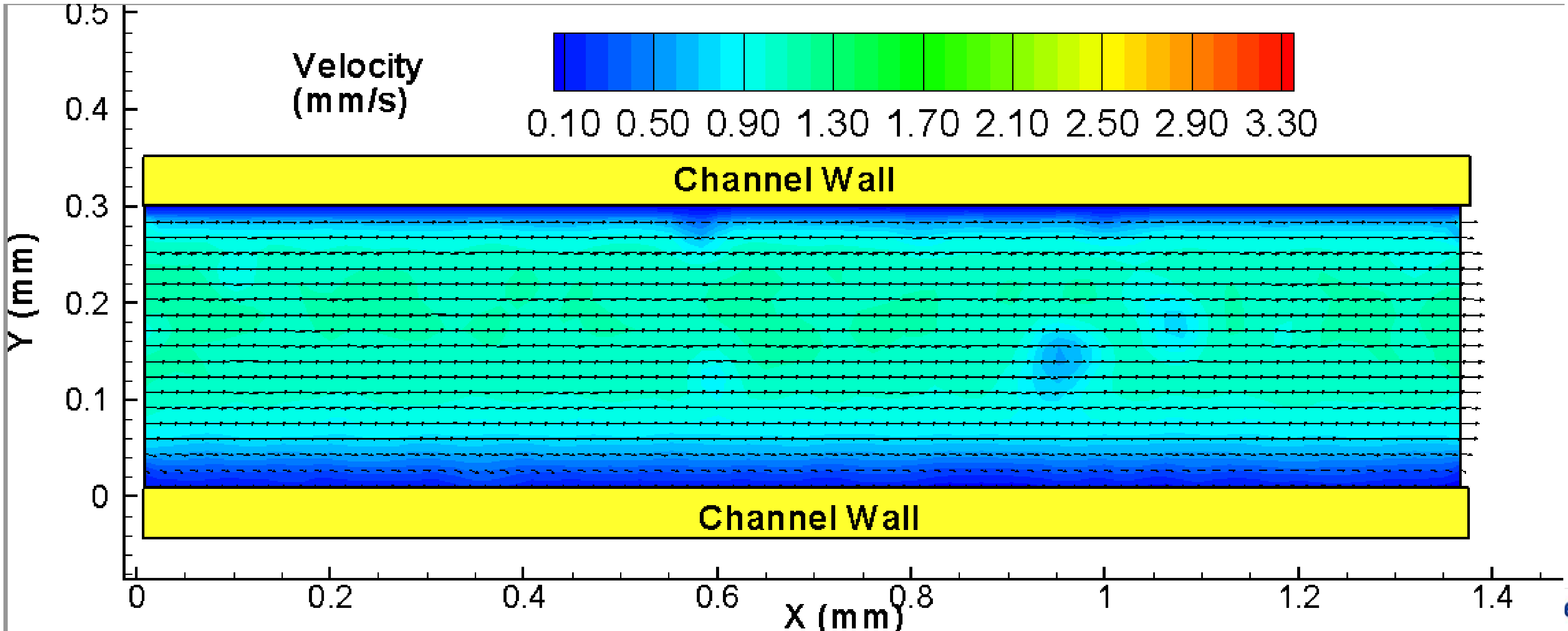






Micro-PIV Measurement Results with Migrating Air Bubbles





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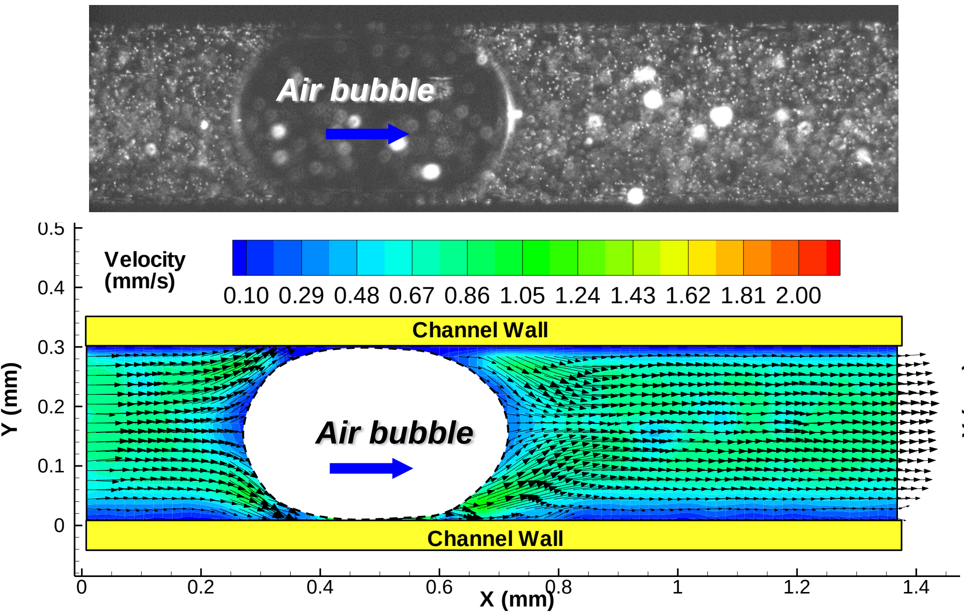
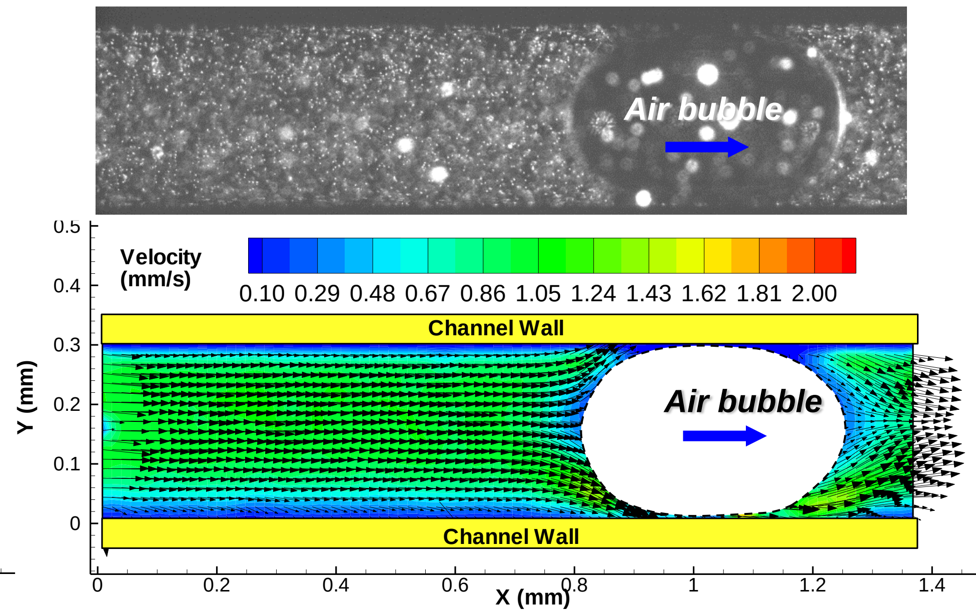
Effects of Migrating Air Bubbles



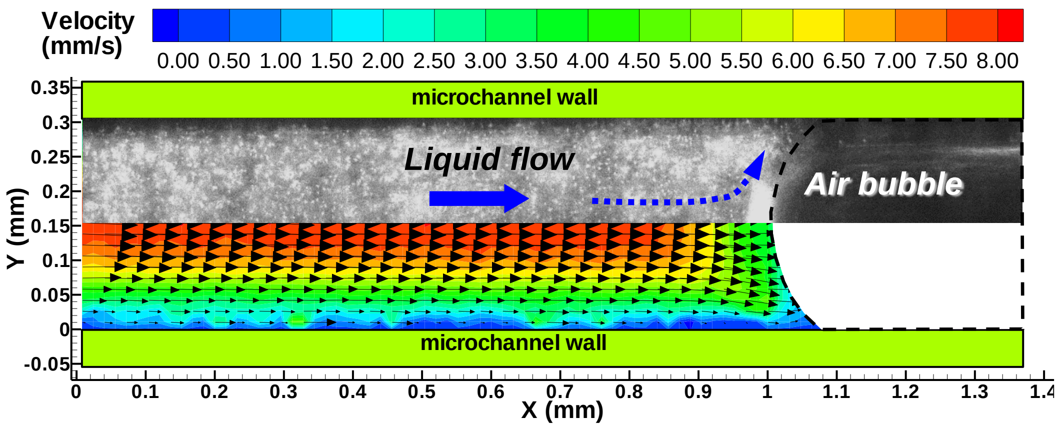
(a). $t = t_0$

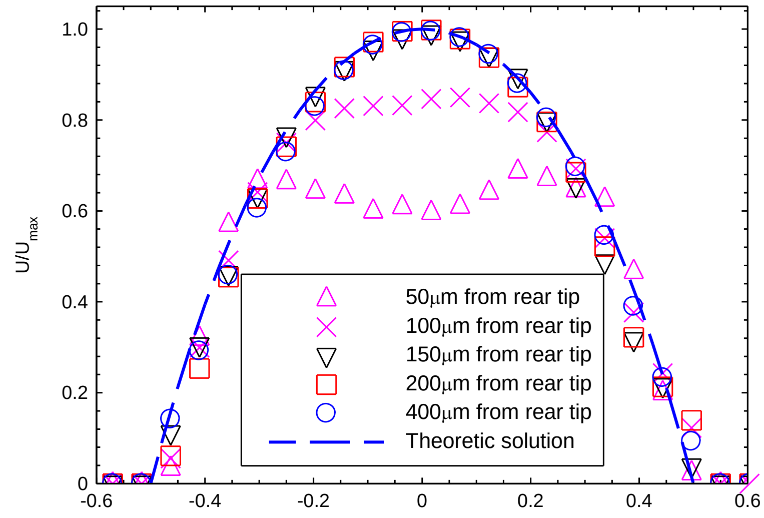


(b). $t = t_0 + 1.8$ s

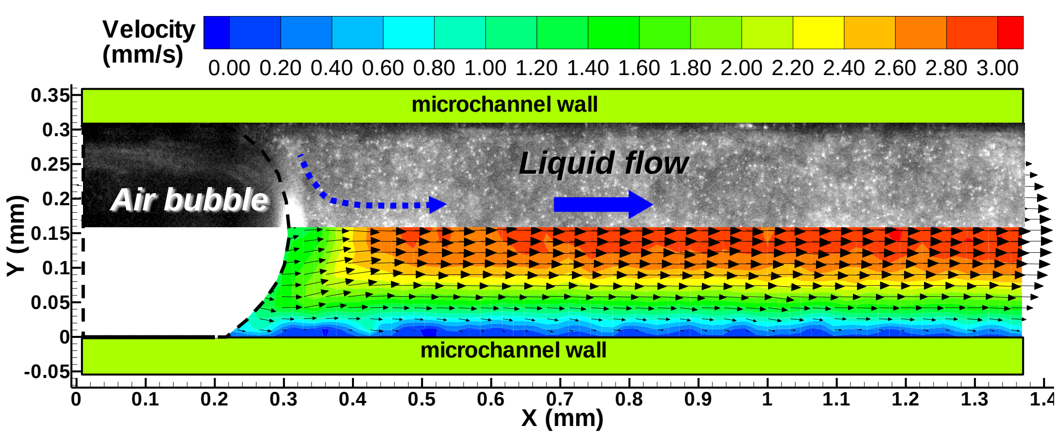
- ***Wang B, Demuren A, Gyuricsko E, <u>Hu H</u>,*** *"An Experimental Study of Pulsed Micro Flows Pertinent to Continuous Subcutaneous Insulin Infusion Therapy", Experiments in Fluids, Vol. 51, No. 1, pp65-74, 2011*

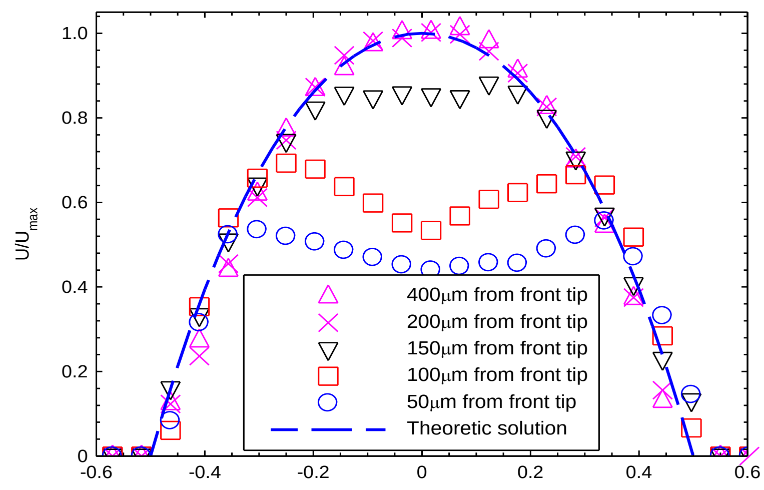
Effects of Migrating Air Bubbles





Near the rear end of the migrating air bubble

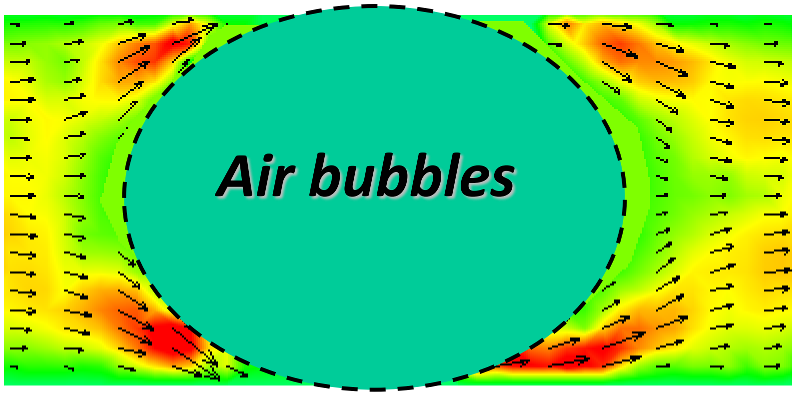


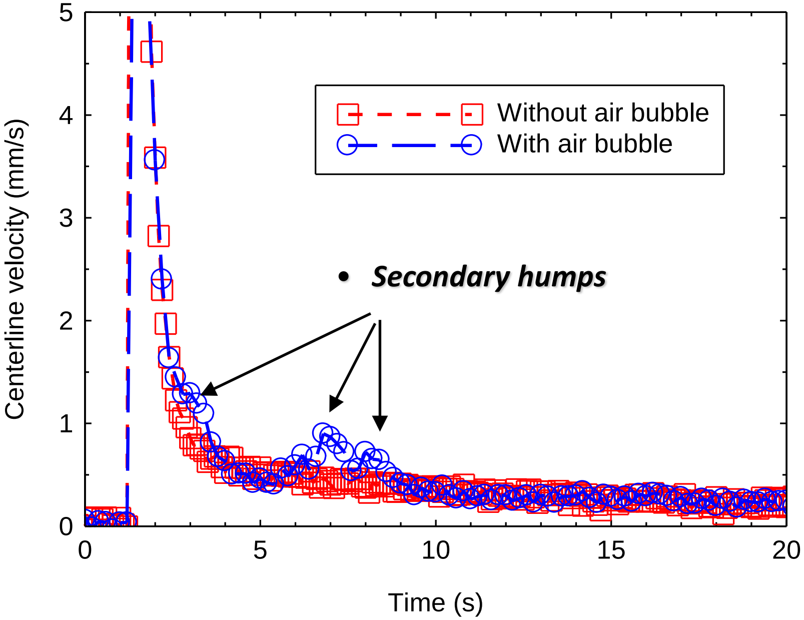


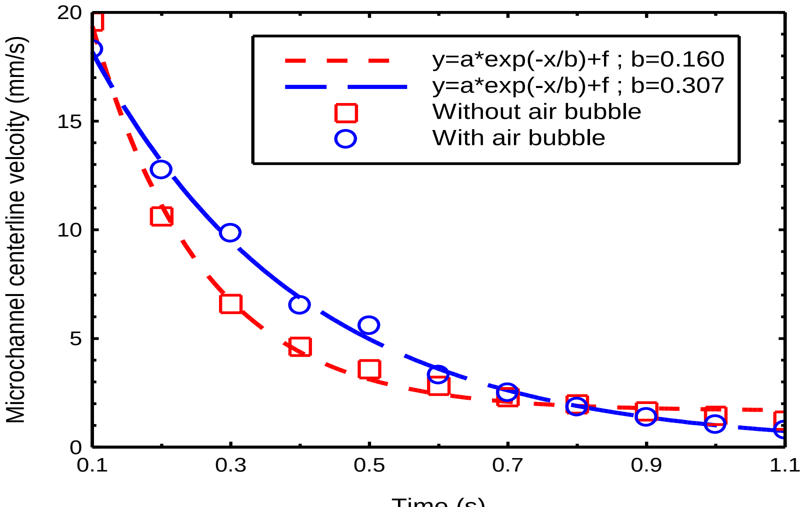
Near the front end of the migrating air bubble

- ***Wang B, Demuren A, Gyuricsko E, Hu H,*** *"An Experimental Study of Pulsed Micro Flows Pertinent to Continuous Subcutaneous Insulin Infusion Therapy", Experiments in Fluids, Vol. 51, No. 1, pp65-74, 2011*

Effects of the Entrained Air Bubbles







- ***The fluid diverges along the interface at the rear side, and converges towards the centerline at the front side.***

- ***Air bubbles tend to soften the initial fast exponential decay due to their compressibility.***

- ***Wang B, Demuren A, Gyuricsko E, Hu H,*** *"An Experimental Study of Pulsed Micro Flows Pertinent to Continuous Subcutaneous Insulin Infusion Therapy", Experiments in Fluids, Vol. 51, No. 1, pp65-74, 2011*